Living in a low carbon city: Wuppertal 2050

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Abstract

The German contribution to limiting global warming to two degrees has to be – as in other developed countries, too – a reduction of 80 to 95 percent of CO_2 emissions by 2050 compared to 1990. The project "Low Carbon City Wuppertal 2050" has analysed how such a drastic reduction of CO_2 could be achieved on a municipal level in the transportation and residential sector by also working on the land use and material flows dimension. The focus of this paper lies on the space heating in the residential sector.

Wuppertal is a city with about 350,000 inhabitants in the West of Germany. According to the CO_2 balance (2007) of the city that was adjusted to the year 2010, the emissions that were caused by space heating in the residential sector remained almost the same since 1990. They decreased slightly from 693,000 tons CO_2 in 1990 to 691,000 tons in 2010, although final energy use for space heating increased by about 15 percent. But the shift of energy sources especially from coal to gas avoided an increase of emissions. However, the reduction target of 95 percent means that CO_2 emissions have to be reduced to 35,000 tons per year until 2050.

A reference scenario shows that the city could achieve about 30 percent of the reduction required with the current trend of renewable energy development and energy efficiency measures such as retrofitting the building stock. But looking at the difficult financial conditions of the municipality as well as at the socio-economic situation of the inhabitants it becomes clear that the remaining 65 percent of the target to a 95 percent reduction will be difficult to reach and that innovative measures of energy efficiency and sufficiency[1] need to be developed.

But which social-ecological effects does the implementation of comprehensive climate protection measures have on the inhabitants of a city? How do people live in a 'Low Carbon City'? In this paper qualitative and quantitative scenarios will be developed since the combination of both is promising to show both effects: what share could renewable energies, energy efficiency and sufficiency measures have in reaching the target of 95 percent, and how could life look like in an almost CO_2 free city in Germany in 2050.

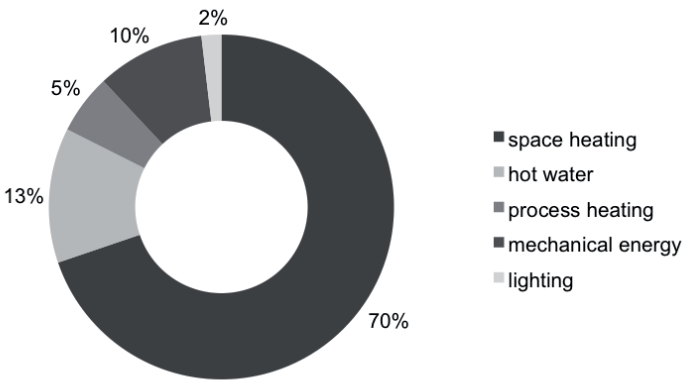
Introduction

The Intergovernmental Panel on Climate Change (IPCC) and the German Advisory Council on Climate Change (WBGU) assert that the industrialised countries including Germany need to reduce their greenhouse gas emissions by 80 to 95 percent by the year 2050 to limit global warming to 2 °C. In the current energy concept, the German Government adapted these targets (BMWi, BMU 2010 b: 5).

WHAT THIS PAPER IS ABOUT

This paper is based on the project "Low Carbon City Wuppertal 2050". In this project the Wuppertal Institute analyses how the targets of the WBGU and the German Government could be realised in different sectors in the City of Wuppertal. What does the achievement of a 80 to 95 percent reduction target look like

1. Sufficiency measures address the scale of consumers' demand, e.g., for dwelling floor space, while energy efficiency measures generaly focus on energy supply and demand.



Source: Wuppertal Institute t.b.p., based on BdEW 2008

Figure 1. Share of ebd uses in the final energy use in private households.

transformed on a specific local level? What would it mean for the mobility or the household sector? What contribution to the reduction can land use or urban mining[2] make?

The following chapters describe possible scenarios that derive from the initial assumption that each sector has to reach the requested emission reduction. For the sector of the private households it was decided to concentrate on the field of space heating due to the fact that space heating has a share of 70 percent on the final energy use in private households[3].

The first part of the paper describes the current situation of private households in Wuppertal and how the development of final energy consumption and CO_2 emissions can be expected in a reference scenario until the year 2050.

The second part shows another almost complementary development of the city. In a narrative scenario it is estimated, that the reduction of 80 to 95 percent of the CO_2 emissions caused by space heating in the residential sector will be reached until the year 2050. The numbers appearing in this narrative scenario are based on the results of the project "Low Carbon City Wuppertal 2050". Methodology, calculations and results will be described very briefly; the focus here lies on the measures and their expected social, economic and ecological effects. Within the framework of the project it was not possible to quantify the reduction potential of single measures, whereas the results can give an idea of the dimension and the direction of a 95 percent reduction.

The combination of quantitative methods and qualitative scenarios provides the opportunity to develop a roadmap to an almost carbon free City of Wuppertal in the year 2050.

A short description of the City of Wuppertal

Wuppertal is located in the west of Germany in a region called 'Bergisches Land' between Düsseldorf, Köln and the Ruhr area. It lies in a 15 km long valley where the river Wupper flows. With an area of less than 170 km² the difference in altitude is up to 350 meters, which led to Wuppertal's nickname 'German San Francisco'. At the end of the 18th century, the industrial development in Wuppertal began at a very early time on the European continent. With a long tradition, the textile industry was most important.

At that time the cities Barmen, Elberfeld and a number of smaller cities existed next to each other and grew as the textile industry grew. In 1929 they were merged to the City of Wuppertal. With the globalisation big parts of the textile industry in Wuppertal went down since the 1970s. Old industrial buildings along the river fell empty, the number of unemployed people increased and the economic relevance of the city came to a low point. With the funding of the university and the development of other sectors like the chemical industry, metal processing, tool and engine construction, Wuppertal experienced a serious structural change. The difficulties that came along with it are not yet overcome.

WUPPERTAL IN THE YEAR 2010

This development, the industrialization and the merging of different cities, as well as the geographical location, built the structure of the city today. The main infrastructural axes lie in the valley along the river. The track of the characteristic suspension railway ('Schwebebahn") in Wuppertal was built over the river around the year 1900 and the old quarters and industrial buildings are situated here; newer parts of the city lie higher on the hillside. The formerly separated parts of the city are still perceptible – the people identify with the district they live in rather than with the city itself.

The economic development of the city had effects on the number of inhabitants, too. From 1990 to 2010 it sank by about 10 percent. Today Wuppertal has about 350,000 inhabitants and is still shrinking. Nevertheless, the living space is increasing; from 1990 to 2010 by almost 8 percent to 14 Million m² (Destatis 2011, Wuppertal Statistics 2011). This means 40,3 square meters are available per person theoretically, but the actual vacancy rate is at about 6 percent. The city is thinking about deconstruction but the vacancies are distributed unequally, the city is perforated. The structure of the owners is very heterogeneous as well especially in the ownership of apartment buildings and blocks of flats, which complicates deconstruction even more. (City of Wuppertal 2009: 27). Most vacancies are, of all districts, in the axis of the valley along the river.

The rate of house building in Wuppertal is at 1 percent while the deconstruction rate is at 0,5 percent. The rate of energetic retrofitting is estimated at 1 percent.

According to the CO_2 balance (2007) of the city that was adjusted to the year 2010 the private households in Wuppertal had a final energy consumption for space heating of about 2,500 GWh in 2010 which equals an average specific space heat demand of the present building stock of 178 kWh/m². Concerning the share of the different energy sources the consumption in the household sector induces CO_2 emissions of about 700,000 tons. The share of renewable energies for space heating in the household sector is estimated at about 3 percent in the year 2010 (City of Wuppertal 2010; Öko-Institut, Prognos 2009).

2. The recycling and the reuse of materials in cities like cables or construction material from deconstructed buildings.

3. Regarding primary energy savings and CO_2 emissions reduction the use of electrical applications has an important role. Due to the framework of the project, it was decided to concentrate on a single field.

Table 1. Final energy consumption for space heating by energy sources in the household sector in Wuppertal 2010.

Heating source	Consumption (MWh)	Share (%)
District heating	243.095	9,8 %
Oil	801.962	32,1 %
Gas	1.205.449	48,4 %
Coal	37.592	1,6 %
Wood	37.592	1,6 %
Electricity	142.849	5,0 %
Heat pump	32.580	1,4 %
Solar heating	5.012	0,2 %
Sum	**2.506.131**	**100 %**

Source: Wuppertal Institute based on the CO_2 balance, City of Wuppertal)

OUTLOOK TO 2050

Existing forecasts estimate that the number of inhabitants in Wuppertal will decrease to about 270,000 persons until the year 2050. The stock of living space will decrease as well to 13.5 million square meters. Still increasing is the personal living space, which will go up to almost 50 square meters in 2050 due to more single-person and larger households. According to a study of the Empirica Consultancy it is possible that the vacancy rate of living space in Wuppertal can increase to more than 11 percent in the year 2025 (Empirica 2007: 49).

Recent climate protection measures in the household sector that have been implemented at the European, the national, the federal and the municipal level focus on energy performance for new houses and support energy efficiency retrofits and the use of renewable energy sources. Taking their effects into account, the space heat demand of the building stock will go down from 2506 GWh in the year 2010 to 1554 GWh with an increasing share of renewable energies to 14 percent until the year 2050. With this development space heating in the household sector will emit almost 500,000 tons of CO_2 in 2050, 28 percent less than in 1990; this is far from the target of a CO_2 reduction of 80 or even 95 percent.

Starting to think from the target – the 80 to 95 percent scenario

METHODOLOGY

The number of inhabitants, the energy performance of existing, renovated and new built houses, the rate of energy efficiency retrofits, the rate of deconstruction and the living space per capita are main factors which influence the final energy demand for space heating in the household sector that were considered in the scenarios. The share of the different energy sources in the sector determines the CO_2 emissions. Considering existing forecasts and studies concerning the development of the number of inhabitants (City of Wuppertal 2007), personal living space (Empirica 2007), achievable energy performances of buildings and a possible future share of renewable energies (Öko-Institut, Prognos 2009), these factors were varied until the CO_2 emissions showed a reduction of 80 percent and 95 percent in the year 2050 against 1990. Table 2 shows the main assumptions and results of the scenario.

FROM THE RESULTS TO THE MEASURES

The results show that it is improbable that the business as usual development in Wuppertal will follow a path to a sustainable situation with regard to the space heating in the housing sector with the recent measures. Therefore, it seems to be necessary to develop a comprehensive action plan to reach these ambitious targets. The developed measures are set on a broad basis. They use various instruments like the administrative and the planning law, financial support, qualification and communication. They address all relevant stakeholders including the administration of the city, planners, craftspeople, the financial sector, energy suppliers and all other affected persons. In this package, they have the potential to lower adverse effects and to strengthen the positive effects of single measures.

In the following chapter, a possible development of the City of Wuppertal is described in a narrative scenario. In four steps of ten years each, the future years from 2010 to 2050 are described estimating that Wuppertal takes a courageous way of sustainable development in the household sector. A bundle of measures and their effects on the main influences of the energy consumption as well as political, social and economic effects will be mentioned. Some of the main measures will be described in more details in each decade. In this way the following text is a foresight with a 'Happy End' in the sense that the City of Wuppertal reaches a reduction of 95 percent of CO_2 emissions compared to 1990 for space heating in the household sector.

The Transformation to a low carbon city

WUPPERTAL IN THE YEAR 2020

Based on the European Energy Efficiency Plan 2011 (European Commission 2011) the German Government initiated a project in which municipalities were requested to develop innovative concepts to lower the space heating demand in the residential sector drastically until 2030. The City of Wuppertal had realised that it is far from achieving the necessary long-term targets with the existing measures. Therefore, the administration initiated long and intense discussions with various stakeholders

Table 2. Main assumptions and results for the reference, the 80 percent and the 95 percent scenario.

Reference scenario		**2010**	**2020**	**2030**	**2040**	**2050**
Population		348.271	348.271	348.271	348.271	348.271
Floor space per capita	m^2/Cap	40,3	43,3	46,7	48,3	49,9
Renovation rate	%/10a		10%	10%	10%	10%
Deconstruction rate	%/10a		5%	5%	5%	5%
Rate of new buildings	%/10a		7%	13%	15%	16%
Average specific space heat demand	kWh/m^2a	178	162	143	128	110
Final energy use space heating	GWh	2.506	2.458	2.118	1.822	1.555
Share of renewables	%	3%	6%	9%	12%	14%
CO_2 emissions	t	691.256	621.856	559.134	519.713	497.905
versus 1990	%	0%	-10%	-19%	-25%	**-28%**
CO_2 per capita	t/cap	1,98	1,88	1,78	1,78	1,83
versus 1990	%	11%	5%	0%	-1%	**3%**
80% scenario		**2010**	**2020**	**2030**	**2040**	**2050**
Population		348.271	348.271	348.271	348.271	348.271
Floor space per capita	m^2/Cap	40,3	43,3	46,7	46,7	45,0
Renovation rate	%/10a		12%	15%	20%	25%
Deconstruction rate	%/10a		5%	5%	10%	10%
Rate of new buildings	%/10a		7%	13%	16%	16%
Average specific space heat demand	kWh/m^2a	178	159	133	90	49
Final energy use space heating	GWh	2.506	2.270	2.121	1.720	1.309
Share of renewables	%	3%	14%	23%	30%	34%
CO_2 emissions	t	691.256	638.035	452.573	256.248	140.157
versus 1990	%	0%	-8%	-35%	-63%	**-80%**
CO_2 per capita	t/cap	1,98	1,93	1,44	0,88	0,52
versus 1990	%	11%	8%	-19%	-51%	**-71%**
95% scenario		**2010**	**2020**	**2030**	**2040**	**2050**
Population		348.271	348.271	348.271	348.271	348.271
Floor space per capita	m^2/Cap	40,3	40,3	39,5	38,8	38,0
Renovation rate	%/10a		15%	20%	25%	26%
Deconstruction rate	%/10a		10%	10%	10%	10%
Rate of new buildings	%/10a		5%	8%	10%	11%
Average specific space heat demand	kWh/m^2a	178	151	115	64	2
Final energy use space heating	GWh	2.506	2.012	1.527	968	358
Share of renewables	%	3%	17%	32%	47%	61%
CO_2 emissions	t	691.256	485.361	295.671	140.541	37.312
versus 1990	%	0%	-30%	-57%	-80%	**-95%**
CO_2 per capita	t/cap	1,98	1,47	0,94	0,48	0,14
versus 1990	%	11%	-18%	-47%	-73%	**-92%**

Source: Wuppertal Institute t.b.p. based on forcasts of the City of Wuppertal (population development), Empirica 2005 (floor space development) and Öko-Institut, Prognos 2009 (heating sources)

and a broad public participatory process to develop an ambitious programme for the household sector called 'Living Space and Redevelopment Programme'. The Programme consists of four main measures:

- an overall concept for a citywide redevelopment and energetic retrofit of the residential building stock,
- an energetic renovation obligation for existing buildings,
- a revolving fund for the necessary investment costs of the refurbishment and
- a 'House Exchange Programme'.

Wuppertal presented a convincing concept receiving high reductions. Therefore, the city – next to other municipalities – received the opportunity to implement the concept with a financial support. The German Government decided as well to provide the legal preconditions to implement energetic renovation obligations.

The combination of a renovation obligation and a revolving renovation fund

When the idea of an obligation for retrofitting existing homes to energy efficient buildings became public first in the draft of the energy concept of the German Government (BMWi, BMU

2010 a) in the year 2010, many doubts appeared from different sides. Associations of property owners suspected that the high costs for the renovations would be an extraordinary burden for the owners. On the other hand, the Tenants' Protection Association noted that the owners would increase the rental fees, which would be a hardship for the tenants especially for low-income households. The discussion confirmed that the investment costs are one of the main obstacles for energetic renovation on a voluntary basis (Stieß et al 2010), although many energy efficiency measures are long-term cost-effective.

In the 'Living Space and Redevelopment Programme' a renovation obligation for existing buildings is combined with a renovation fund to distribute the investment costs for the necessary refurbishments from single groups to all inhabitants with a main focus on the socio-economic suitability. The main part of the municipal award, the municipal budget and a contribution of each citizen financed the original investment for the revolving fund. The private contribution was an obligatory one-time payment graded according to the income of the households.

Of course this point was the most sensitive part of this measure. Therefore, it was discussed broadly in public and accompanied by a comprehensive information campaign. The obligation first seemed to be necessary to raise the start-up capital for the fund. But in the year 2020 it also becomes clear that the obligatory participation on the fund not only means that each citizen contributes to the citywide redevelopment. It also provides a strong incentive for the owners to utilise the fund to renovate their own properties. The rate of energetic retrofitting increased to almost 2 percent. It is estimated that it will go up to about 3 percent by the year 2050.

The costs for energetic renovation and the integration of renewable energy systems are financed by the fund. An energy consultant assesses the actual energy demand and the possible savings. As in an energy performance contracting agreement, the owner and the city (as the fund administrator) contract that the assessed savings flow into the fund for an agreed period of time to replenish the fund. If the house is rented the owner is not allowed to increase the rental fees after the renovation. In this way the tenant benefits from less energy costs. The benefit for the owner is an increased value of the building and less vacancies, if the house is rented, especially if he or she participates on the 'House Exchange Programme'.

Because of the perforated and disperse structures of Wuppertal in terms of unoccupied flats and the numerous owners of properties and buildings, the former contracting concepts needed to be adapted to the local specifics. Wherever possible, buildings of similar construction or neighbouring buildings are compiled to one refurbishment project to achieve synergies and make it more cost-effective. But with the conglomeration of different houses, owners and tenants as well as the integrative aspect of the contracting projects, that involve measures to lower the final energy consumption by thermal insulation, efficient technologies and the integration of renewable energy systems measures, the complexity of the projects is increasing. Therefore, and because of the number of buildings that are supposed to be renovated in the next decades it became necessary to minimize the administrative time and transaction costs.

WUPPERTAL IN THE YEAR 2030

In the year 2030 34 percent of the existing building stock are energetically refurbished. The average specific space heat demand of the refurbished buildings is at 35 kWh/m^2. Next to that 1.7 million square meters of living space in new houses were built which have an average specific space heat demand of 30 kWh/m^2. Next to other measures this is a success of the qualification programme for the local planners and craftspeople. This intensive programme was developed in cooperation with the Chamber of Architects and the Chamber of Commerce and Industry; the courses end with a certificate, which is required in the bid invitations for building projects financed by the fund. The people already living in houses with a high energy performance benefit in particular because the costs for thermal energy in Wuppertal is constantly increasing since 2010[4].

The information campaign reports regularly about the processing of the programme and the success in reducing Wuppertal's CO_2 emissions. In the year 2030, the emissions caused by space heating in the household sector are at 296.000 tons. Other cities in Germany started similar programmes. Their main incentive is to preserve living space for their citizens that they can afford to live in; in some regions energy poverty is a serious problem in 2030. Therefore, the 'House Exchange Programme' becomes more and more popular.

The 'House Exchange Programme'

The basis for the programme is a database of residential buildings that provides necessary information like the address, the type of building, the year of construction and the energy performance. In numerous 'House Exchange Bureaus' all over the city tenants and owners can ask for advice if

- they are looking for a house or a flat with a high energy performance,
- they have vacancies in their refurbished property that they want to rent or to sell,
- their house is going to be refurbished and they need a temporary flat to avoid the discomfort of a renovation, or
- they want to exchange their property in a deconstruction area[5] with a property in a development or regeneration area.

The employees at the bureaus advise the clients concerning vacancies, refurbishment necessities and possible payments by the fund. But they also play an important role in the cooperation between municipality and inhabitants. They provide information about the 'Living Space and Redevelopment Programme', organize renovation alliances, explain the targets of the City of Wuppertal in the residential sector, they promote the necessity of contribution and support of the inhabitants of Wuppertal, as well as economic and other benefits of energetic refurbishment. Concerning the aspect of communication the cooperation with the former 'District Development Corpora-

4. In an estimation the Facility Management of the City of Wuppertal came to the following yearly rates of price increase: oil: 12 percent, natural gas: 10 percent, district heating: 6,7 percent (GMW 2007).

5. The redevelopment concept of the City of Wuppertal is focussing the concept of a'city of short ways'. Therefore, the central districts along the river are stipulated as 'development' and 'regeneration areas' in the urban development plans, wheras 'deconstruction areas' are stipulated in suburban districts with high vacancies.

tion Wuppertal' (WQG) that was founded in 2006 is beneficial. The WQG had experiences in advising property owners in disadvantaged districts, conducting redevelopment projects and networking. When the financial support of the federal state for the WQG was phased out in 2011 it was possible to transfer the knowledge and structure of the corporation to the new redevelopment programme.

The 'House Exchange Programme' works in a close cooperation with the renovation fund and supports the redevelopment concept of the city. Following the concept the districts along the river in the centre of the city became more attractive again. In other districts buildings are deconstructed and areas renaturalised.

WUPPERTAL IN THE YEAR 2040

In 2040 it becomes apparent that the 'Living Space and Redevelopment Programme' has some positive effects on the economy of Wuppertal. With the rate of renovation, which is at 2,5 percent, the employment rate is rising, too, especially in the fields of installation, planning and energy advice, in the 'House Exchange Bureaus' and the fund administration.

Next to energy efficiency measures and the support of renewable energies in the household sector, concepts for a more sufficient living are another focus of the programme. In the forecasts it became clear that the increase of the personal living space has to be stopped to reach the targets of 80 to 95 percent CO_2 reduction.

Two factors were identified as main drivers for the increase of personal living space: The tendency to more numerous households with less inhabitants and larger dwellings demands a growing supply of houses and flats. A second factor is the demographic change. Elderly people whose children moved out or partners passed away often stay in their houses and flats although the space is not needed any longer. In Wuppertal as a shrinking city with a decreasing number of inhabitants the second factor can be estimated as the more relevant one. Therefore, new housing and neighbourhood concepts were developed.

'Sufficient homes'

Innovative housing concepts with flexible living space, growing and shrinking flats concerning to the actual situation of the tenant (and his or her family), with common areas like washing and drying rooms or guest rooms as well as 'multi-generational co-housing initiatives' exist for several decades already. But in most cases they remain single projects; the majority lives in a more conventional way.

In a close cooperation with the University of Wuppertal an architectural and urban planning competition for new housing concepts was announced. In the development and regeneration areas – concerning to the redevelopment plan of the city – several locations with different characteristics were identified as possible sites for these projects. Some of them were planned in central districts where old buildings needed to be deconstructed, others were developed in old vacant industrial buildings near the Wupper that could be refurbished and converted into unique and unusual residential buildings. But none of the projects was built on undeveloped land.

The demands on the concepts follow a broad approach. Existing concepts and projects were examined and developed further to the specific needs of the growth areas in Wuppertal. Next to a flexibility of the living space and common areas they request an attractive neighbourhood with private and social infrastructure and offers for inhabitants of different socio-economic situations. A mix of functions contributes to the reduction of traffic and the development of a 'city of short ways' by providing the inhabitants with daily necessities and services.

Some of the best ideas has been realised already. They are called the 'Sufficient Homes'. The advisors at the 'House Exchange Bureaus' play an important role promoting the new concepts. As the inhabitants stated in the latest enquiry they do not only benefit from low energy costs because of smaller flats in efficient houses but from a cooperative neighbourhood and a pleasant lifestyle. On a regular basis the district energy advisor visits the projects, talks to the inhabitants and helps them keeping their energy consumption low.

The programme has an influence on the university as well. Students in architecture, urban development, engineering and social studies are involved in several projects. Therefore, it is not only that Wuppertal got some of the most innovative and sustainable housing concepts, but also the university is able to draw more students by offering them an exceptional practice oriented education.

The living space per person decreased to 38,8 square meters in 2040.

WUPPERTAL IN THE YEAR 2050

Wuppertal's latest CO_2 balance shows that the emissions of the residential sector went down to 37,312 tons – 95 percent less than in 1990. This became possible with a consequent development in the fields of energy efficiency, the use of renewable energy and sufficiency. But next to the contribution to climate change mitigation Wuppertal benefits in many ways from this development.

- Almost all residential buildings were retrofitted or were newly built since 2010. Only very few buildings still could not be refurbished. Most of them are buildings under preservation order with very specific constructions.
- The costs for energy consumption in some households rose but to a bearable amount. Others are almost self-sustaining by renewable energy. And others are supplied by the district heating of the municipal utility along the valley.
- The employment rate increased constantly over the last forty years, which had positive effects on the economic welfare of the inhabitants.
- The districts in the valley were shrinking most in 2010. Old industrial buildings along the river, most of them vacant, run down and some of the estates contaminated, characterised these areas. Nowadays, they have developed to liveable and growing districts that attract many people in Wuppertal.

The redevelopment concept

In 2050 the redevelopment of the City of Wuppertal is almost finished. The concept was developed for the 'Living Space and Redevelopment Programme' in 2011 with a main focus on a sustainable urban development concerning traffic, housing and green areas.

Along the river a 'green belt' was developed with smaller parks, gardens and a path for cyclists and pedestrians. Along the hillside the closed building structure was carefully opened with green areas. These urban recreation areas are very well accepted by the inhabitants, improve the climate in the valley and lower the particulate matter exposure especially during the very hot summers. Like this they contribute to climate change adaptation as well.

With the redevelopment concept, the City of Wuppertal decided to strengthen the central districts along the river aiming towards a 'city of short ways'. Some peripheral areas were identified as 'deconstruction areas'. The main indicators were inefficient buildings with a high demand for renovation and a high rate of vacancies. The deconstruction became necessary because of the decreasing number of inhabitants in Wuppertal and the forecast that rate of vacancies would increase even more. In 2050 the former 'perforated city' has developed to a smaller but concentrated city.

Review and conclusions

The scenario of the transformation of the City of Wuppertal above is 'science fiction' in its literal meaning of the word: Science contributes data and numbers, fiction the ideas of what the development could look like. Sketching the direction of the path and the dimension of required developments with regard to

- energy performance of existing and new built houses,
- rate of energetic retrofitting,
- rate of deconstruction,
- personal living space and
- share of renewable energies

show impressively that the target of a 80 to 95 percent reduction of CO_2 emissions is very ambitious and will not be reached with the recent path and recent measures.

In a first step the administration of the City of Wuppertal has to design a model of a sustainable urban development for the city regarding the circumstances of a shrinking city and the economic situation. For the development and implementation of measures, programmes and concepts in a next step the cooperation with relevant stakeholders like the municipal utility, the local banks, the Chamber of Commerce and Industry, the Chamber of Architects, the 'District Development Corporation Wuppertal' and others is important. And of course the inhabitants of Wuppertal should be involved regularly in a broad public participation and cooperation process especially with regard to the more sensitive measures mentioned above.

The results of the project 'Low Carbon City Wuppertal 2050' show how it could be possible to achieve a reduction of the CO_2 emissions by 80 to 95 percent against 1990 of space heating in the household sector. But they show, too, that this target is very ambitious. As it is described here, the City of Wuppertal – as many other municipalities, too – needs support from action plans, programmes and initiatives on the European and the national level especially with regard to European Directives or national legislation and finance. With such a framework in place, the City of Wuppertal would be able to develop a climate protection concept and to implement a broad and courageous package of measures that contribute to a more sustainable development and decrease the emissions of the city significantly.

References

City of Wuppertal, 2010. eea-Bericht. Externes Audit Stadt Wuppertal Endfassung 2010. Wuppertal, Germany.

City of Wuppertal, 2007. Bevölkerungsprognose 2007. Wupperal, Germany

Empirica GmbH, 2007. Stadtumbau-West: Städtebauliches Entwicklungskonzept Wuppertal – Endbericht. Bonn, Germany.

European Commission, 2011. Energy Efficiency Plan 2011. Brussels, Belgium.

German Advisory Council on Climate Change (WBGU) 2009. Kassensturz für den Weltklimavertrag – Der Budgetansatz. Berlin, Germany.

Intergovernmental Panel on Climate Change, 2007. Climate Change 2007 – Synthesis Report. Geneva, Switzerland.

Facility Management of the City of Wuppertal (GMW), 2007. Entwicklung der Energiepreise und der Energiekosten und die daraus zu ziehenden Konsequenzen. Anlage zu Drucksache VO/1016/07. Wuppertal, Germany.

Federal Ministry of Economics and Technology (BMWi); Federal Ministry for the Environment, Nature Conservation and Nuclear Saftey (BMU), 2010 a. Entwurf: Energiekonzept. Neun Punkte für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung. Berlin, Germany.

Federal Ministry of Economics and Technology (BMWi); Federal Ministry for the Environment, Nature Conservation and Nuclear Saftey (BMU), 2010 b. Energiekonzept für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung. Berlin, Germany.

Federal Statistical Office (Destatis), 2011. Wohngebäude- und Wohnungsbestand. www.destatis.de.

Öko-Institut; Prognos, 2009. Modell Deutschland. Klimaschutz bis 2050. Vom Ziel her denken. Basel, Switzerland; Berlin, Germany.

Stieß, I.; van der Land, V.; Birzle-Harder B.; Deffner, J., 2010. Handlungsmotive, -hemmnisse und Zielgruppen für eine energetische Gebäudesanierung – Ergebnisse einer standadisierten Befragung von Eigenheimsanierern. Frankfurt am Main, Germany.

Wuppertal Institute, to be published. Low Carbon City Wuppertal 2050. Wuppertal, Germany

Wuppertal Statistics, 2011. Population in the City of Wuppertal. www.wuppertal.de.

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